

THE “LIFE ON MARS” HYPOTHESIS

Mars Meteorite Research Team
NASA Johnson Space Center

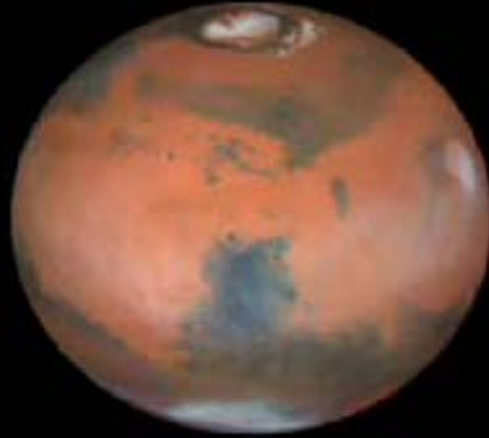
Scientific Perspective



In 1996 our team announced that Martian meteorite ALH84001 contained evidence for ancient Mars life

- Why is the search for extraterrestrial life important?
- How do we define life?
- What is our most convincing evidence for ancient life on Mars?

What is the Major Question?



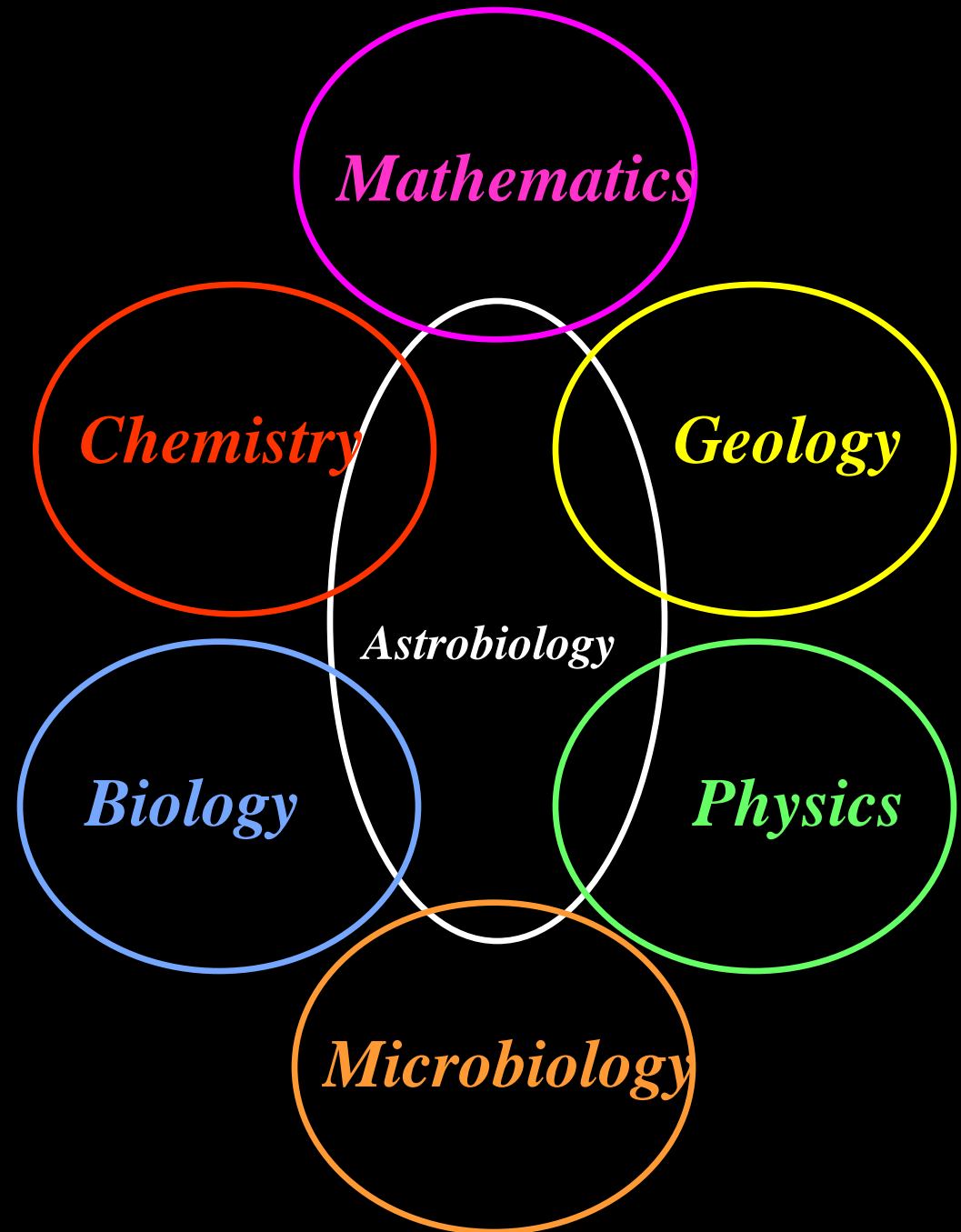
Is there life outside of the bounds
of Earth?

P.S. -- we don't care if it is intelligent
or intellectually challenged life

Why is Life on Other Worlds Interesting?

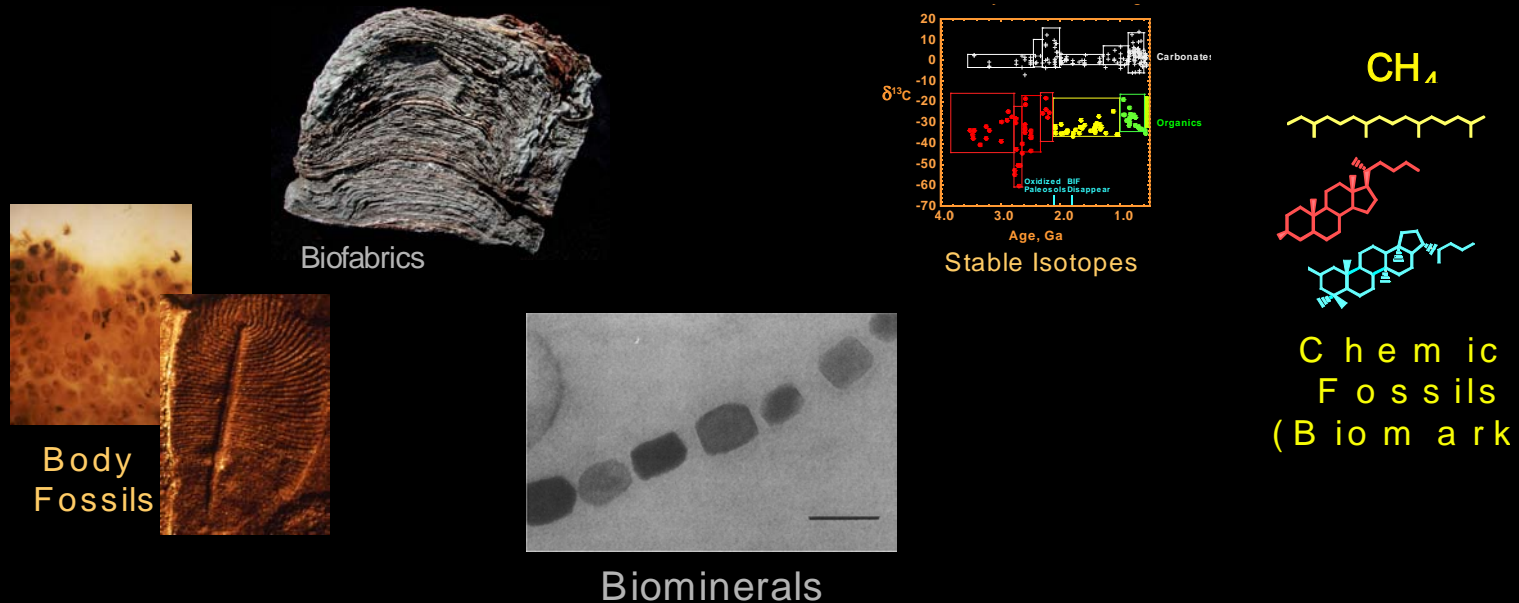
- The possibility of a second genesis of life:
 - ⇒ comparative biochemistry
 - ⇒ life is common in the universe(?)
- Information about the early planetary environment (*i.e.*, water, organics, magnetosphere)
- Relevant to the origin of life on Earth

**Scientific disciplines
that comprise
Astrobiology**



A Major Goal

In Martian meteorites is to search for and classify *biosignatures*—fingerprints of present and/or past microbial life.



Definition of biosignature: measurable physical and/or chemical markers of life that do not occur through random, stochastic interactions nor through the product of directed human intervention.

Assumption: looking for life on Mars means looking for unicellular organisms that share traits with terrestrial organisms

Justification: identification of a Martian biosignature will have to be made by analogy to terrestrial life, as this is only form of life we know

Why Mars?

Mars is the nearest planet for which the search for evidence of life is justified:

- Earliest Mars preserves record of conditions and materials from which LIFE could have started
- Even today there are places on Mars that are “habitable”



Mars is so much like Earth (yet surprisingly different)

- Silicate planet with an atmosphere, hydrosphere, and climate
- Ancient magnetosphere

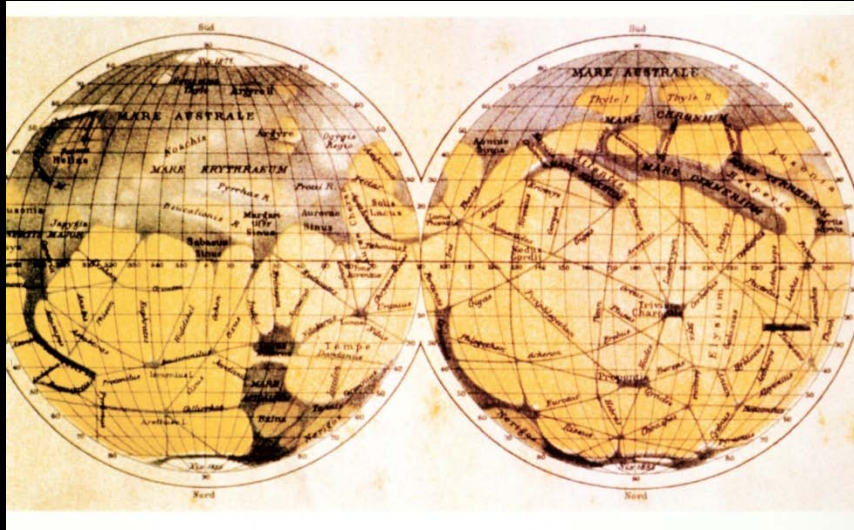


Mars inspires, both scientifically, and as a tangible frontier

- Life on Mars hypothesis (McKay et al., 1996), while controversial, has not been refuted
- Research today will provide the knowledge needed to decide when/where to send human explorers to the Red Planet.

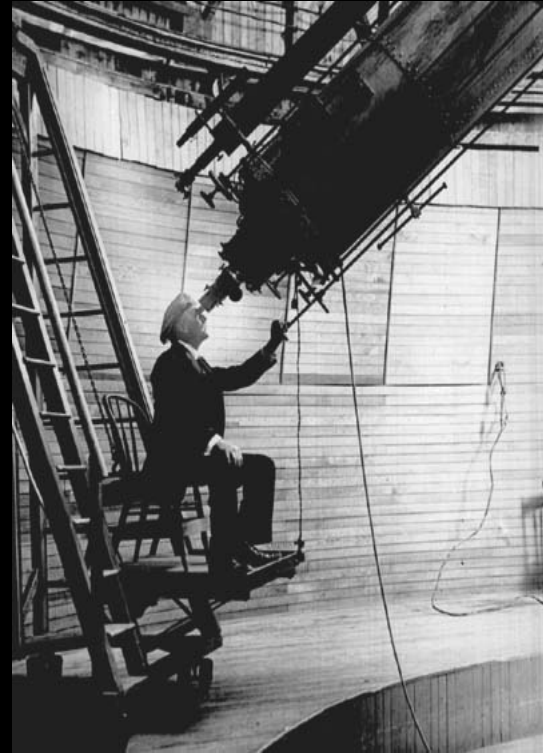
Giovanni Schiaparelli (1835-1910)

Canals on Mars



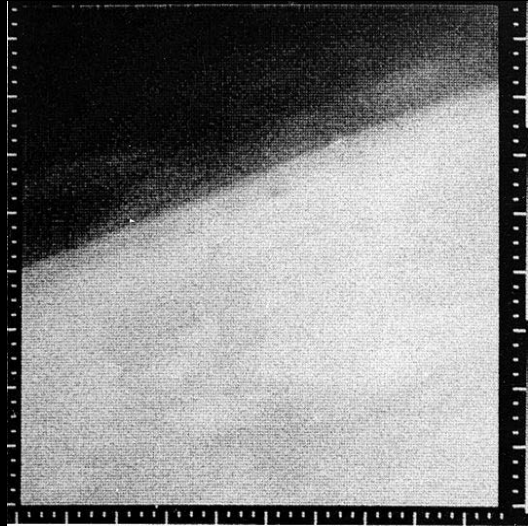
Percival Lowell (1855-1916)

Advanced Civilizations on Mars



1965: First Photos from Mars

U.S. Mariner 4 Spacecraft



First image of Mars



**Famous picture
#11**

Successful flyby on July 15, 1965

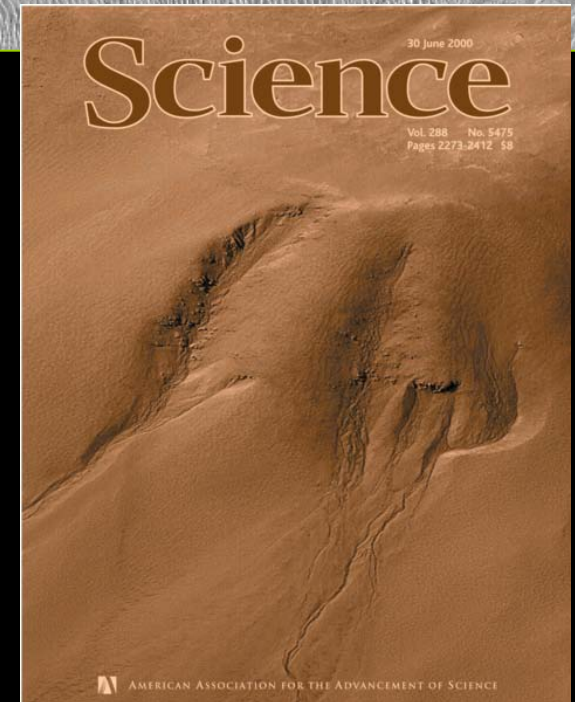
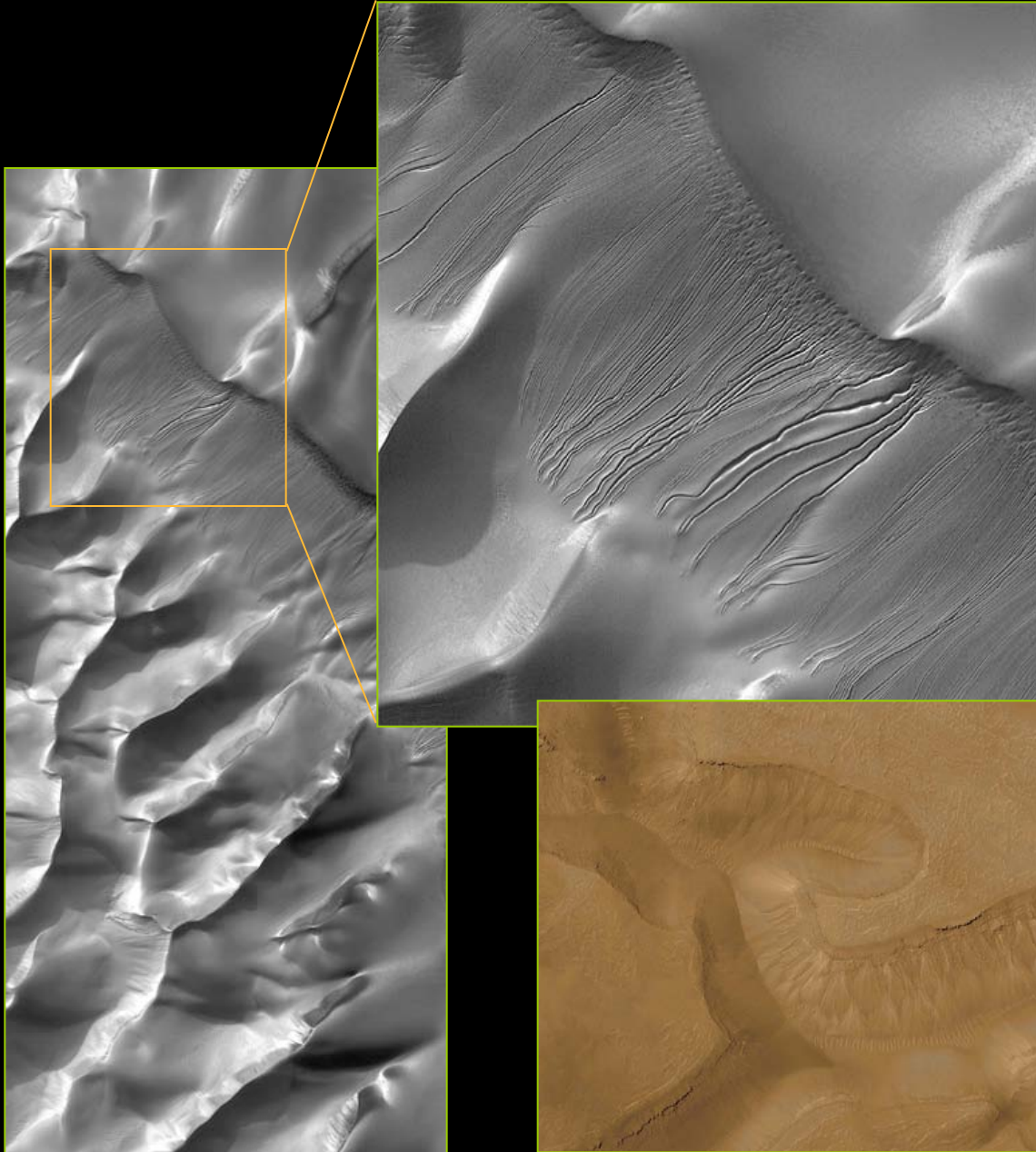
1976

First Viking Image from the Martian Surface -- First landing on Mars!



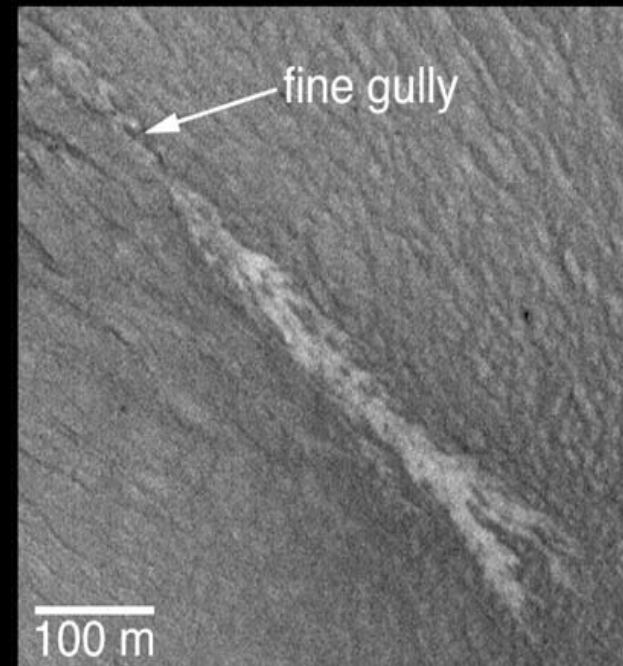
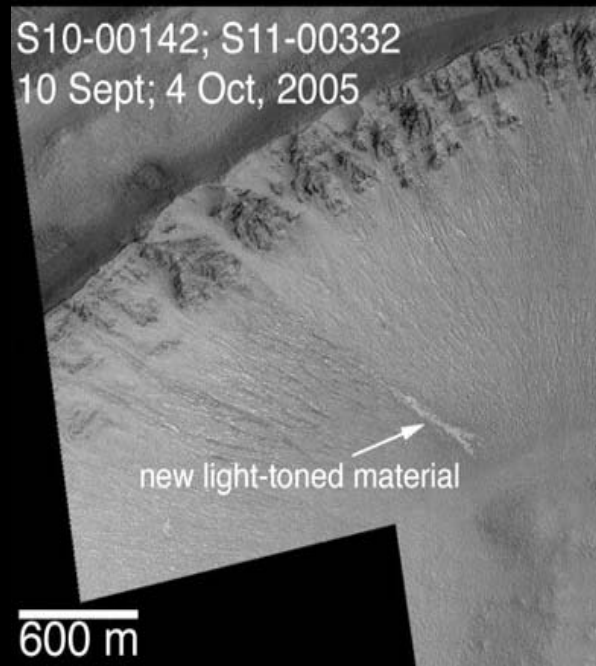
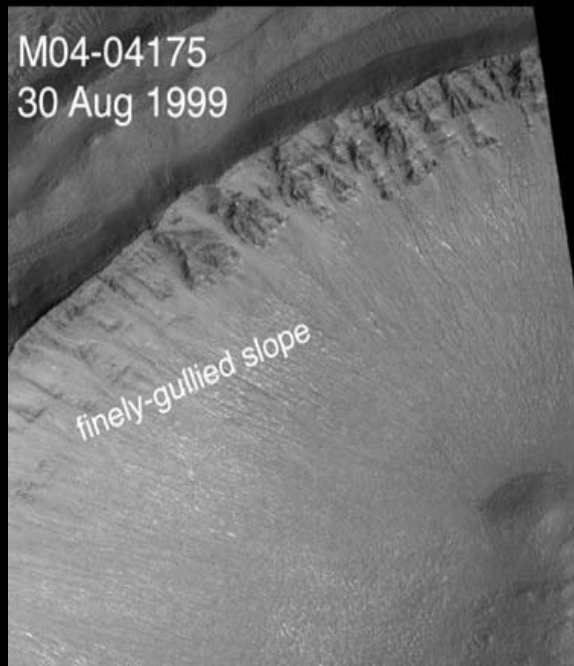
Received by JPL 19 minutes after this image was taken

Martian Gullies: Watersigns

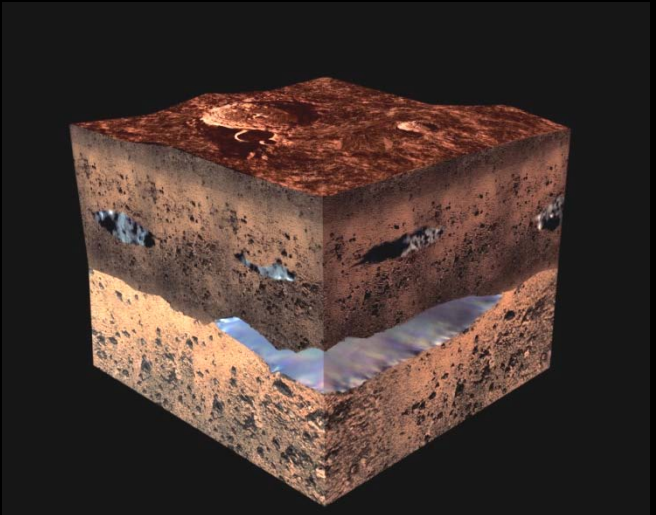
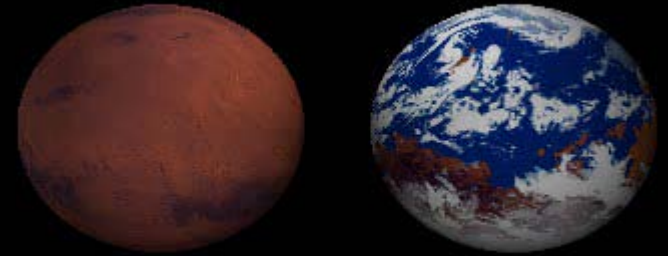
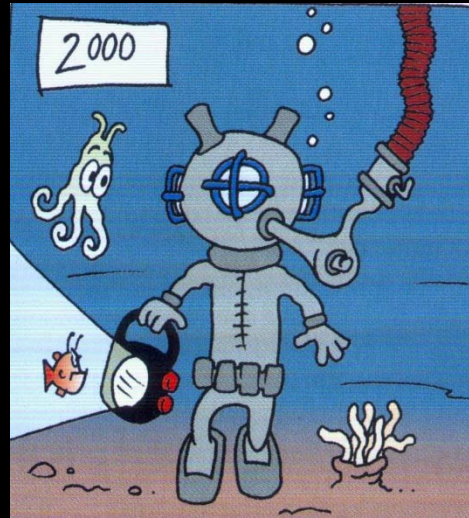
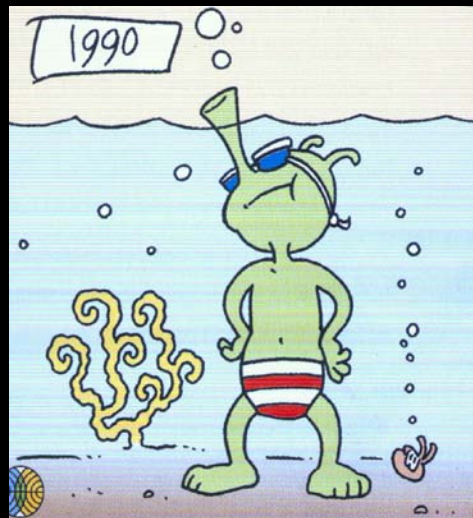
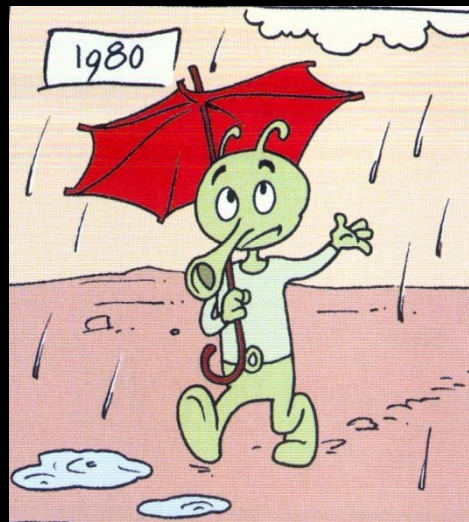


Changing Appearance of Martian Gullies

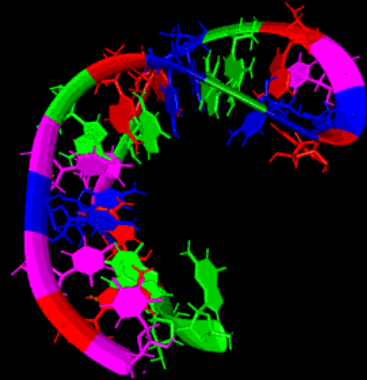
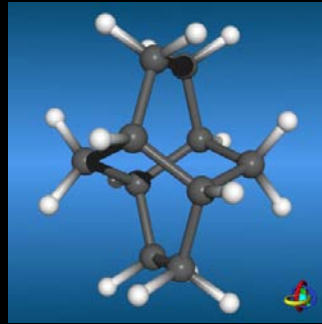
Water “Squirting” from Canyon Walls



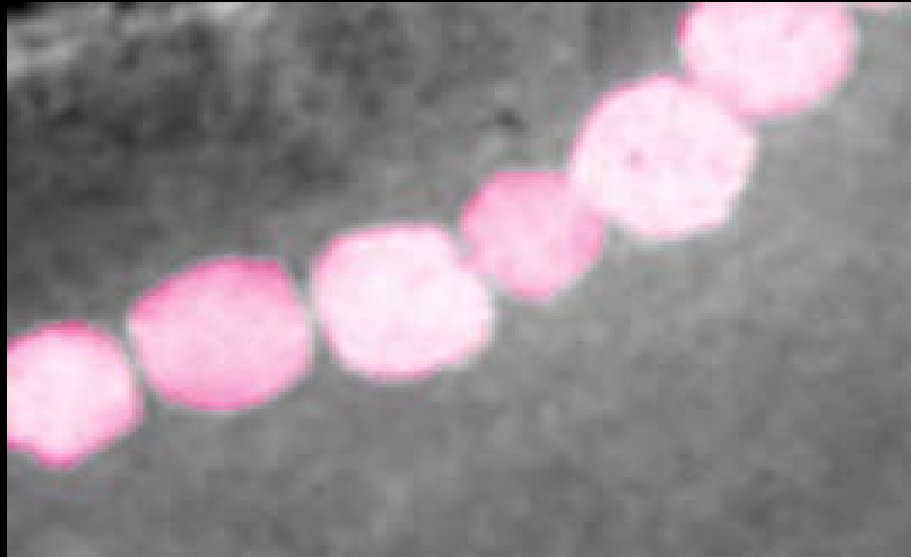
Changing Perceptions of Water on Early Mars



Definition of Life?

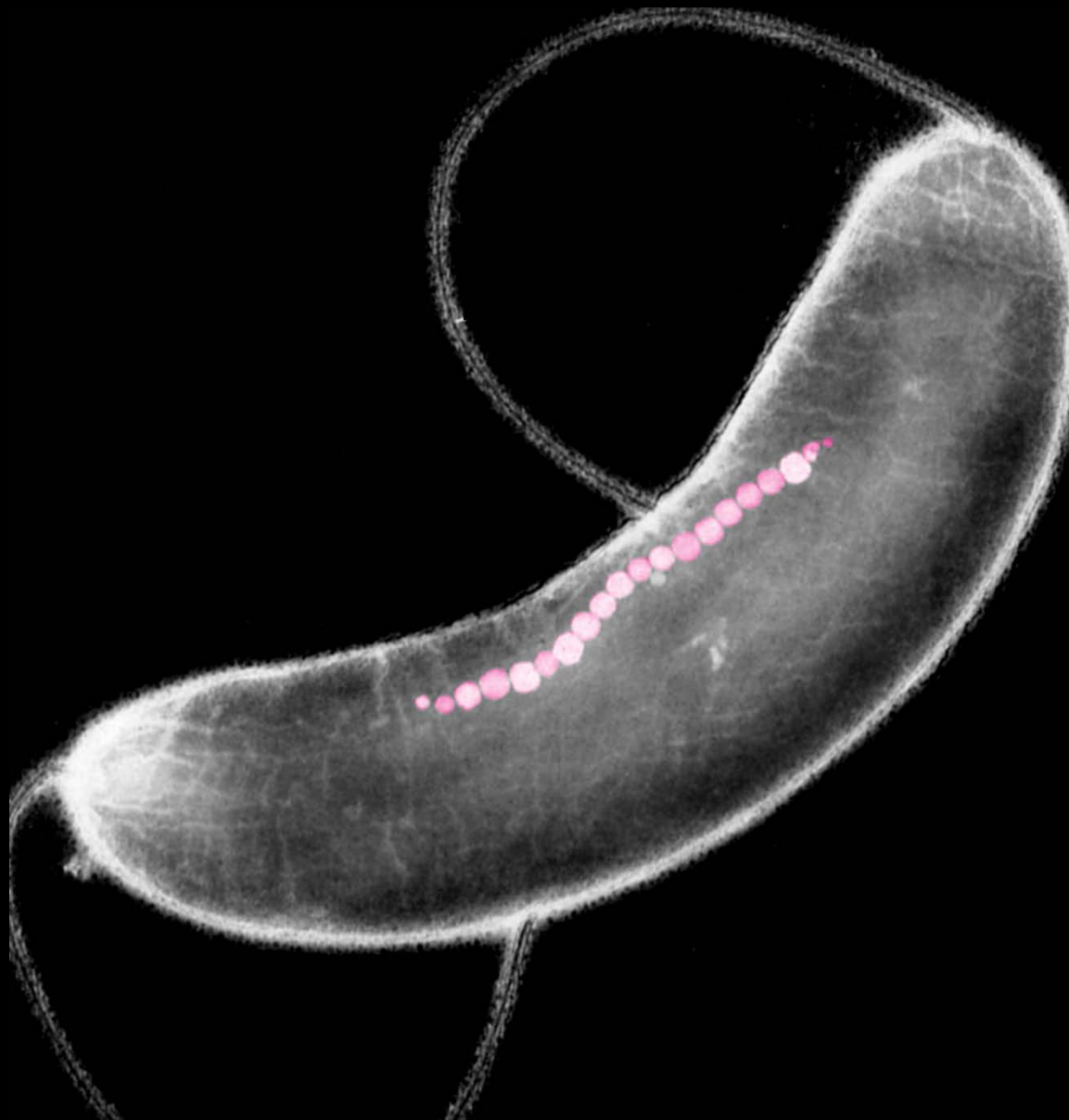


Life or No Life?



|<----->|
100 nanometers

Magnetotactic Bacteria



|<-->|

200 nm

Mars Habitability Index

- Requirements for habitability include:

- ✓ Solvent (water)
- ✓ Energy source(s) (solar, hydrothermal, geochemical)
- ✓ Carbon source(s) (CO₂; meteoritic influx)
- ✓ Magnetosphere (this may not be a firm requirement, but it helps)

Biosignatures

- **No single piece of evidence may be convincing for the presence of life**
- **Observation of multiple lines of evidence may, as a whole, be taken as convincing evidence for life : a related suite of features**

**Spatially associated, multiple,
independent biosignatures
required for confirmation of life**



MARS ROCKS

Meteorites from Mars -- Poor-Man's Sample Return

How many? ~ 53 (10/2009)

(new ones continue to be found on Earth)

How much weight? ~ 92 kg

**(note that this is about 10% of the entire Apollo
sample mass returned by the astronauts)**

Crystallization ages: *4.5 Ga to 165 Ma*

Aqueous alteration: *3.9 Ga to <165 Ma*

**Age ranges span most of the geologic history
of Mars**

Examples of Martian Meteorite Ages (in millions of years)

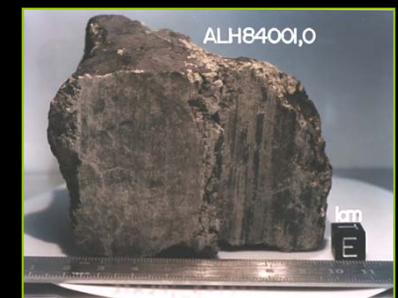
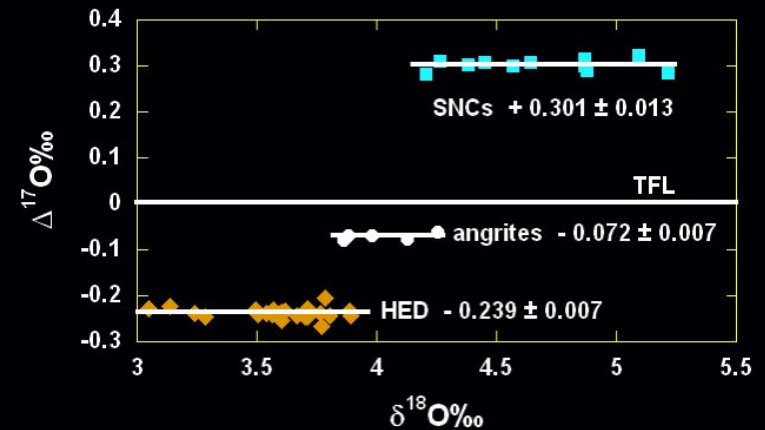
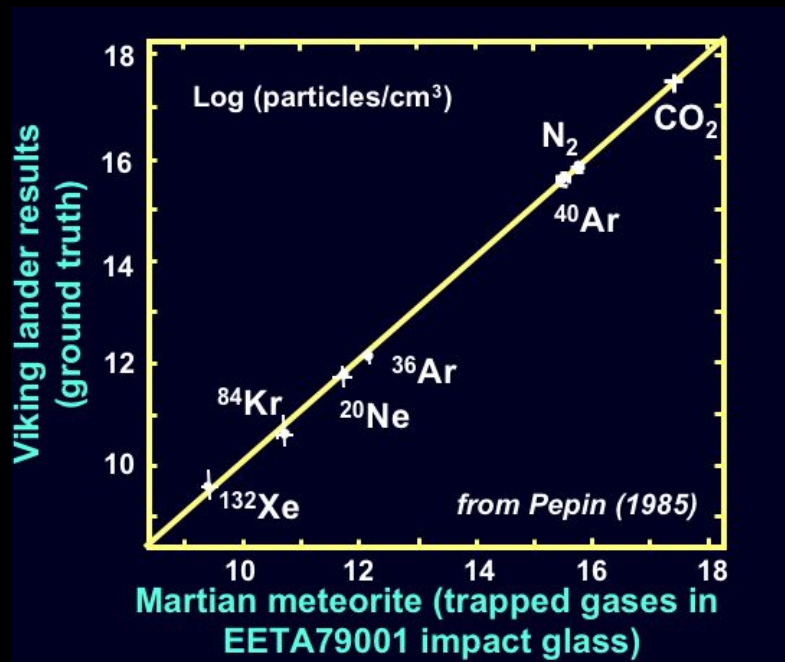
Shergottites	Nakhiltes & Chassignites	Orthopyroxenite
<p> Shergotty Zagami Los Angeles EETA79001 ALHA77005 LEW 88516 </p> <p>~165-180</p> <p> Y793605 QUE 94201 DaG 476, 489, 735, 670, 876 Dhofar 019 </p> <p>~212-600</p>	<p>~1300</p> <p> Nakhla Gov. Val. Lafayette Chassigny </p>	<p> ~4500 whole rock ~3900 carbonates </p> <p>ALH84001</p>

Planet of Origin: Mars

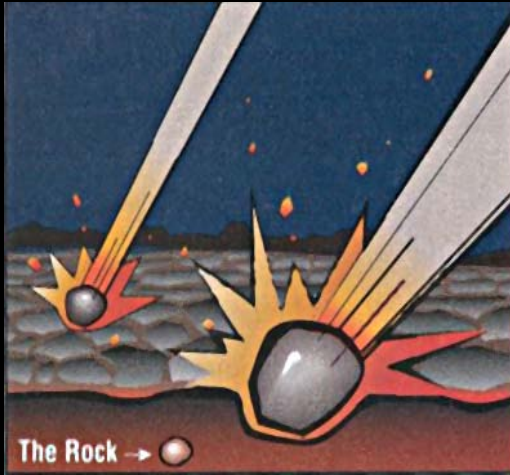
From the Viking analyses, bulk composition of martian atmosphere is not like any other known source of gas



Unique Oxygen In Silicate Minerals



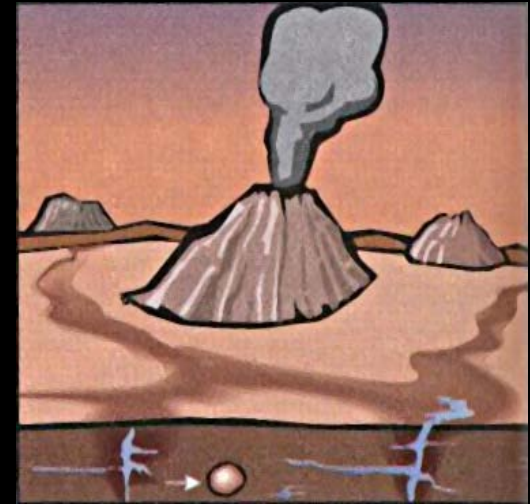
The History of Martian Rock ALH 84001



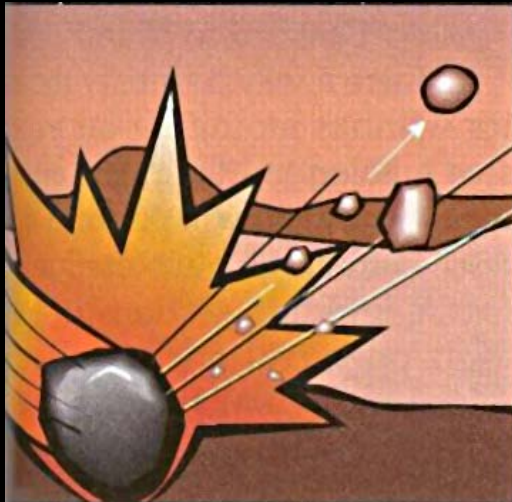
Mars 4.5 billion years ago



4.0 billion years ago



3.9 billion years ago



16 million years ago



16 million years in space



Earth 13,000 years ago

ANSMET

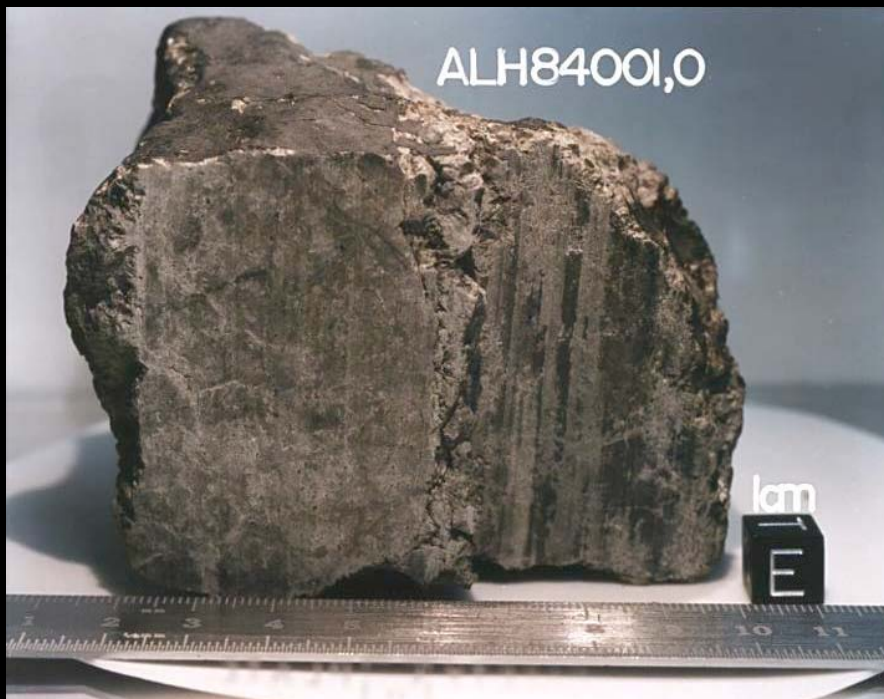
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Antarctic Search For Meteorites Program

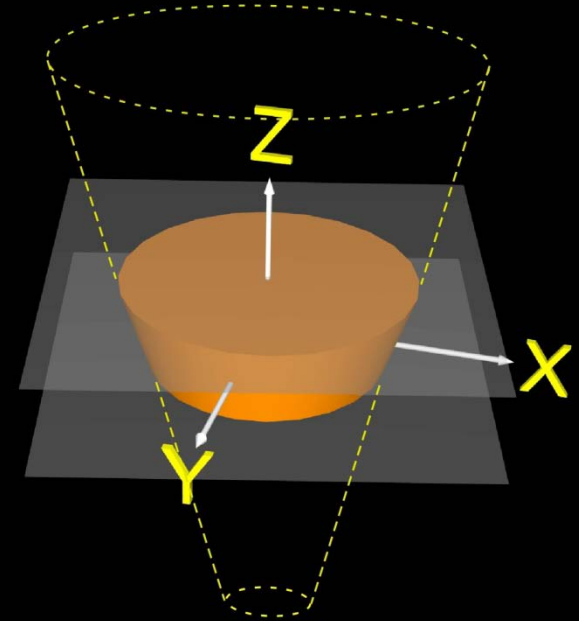
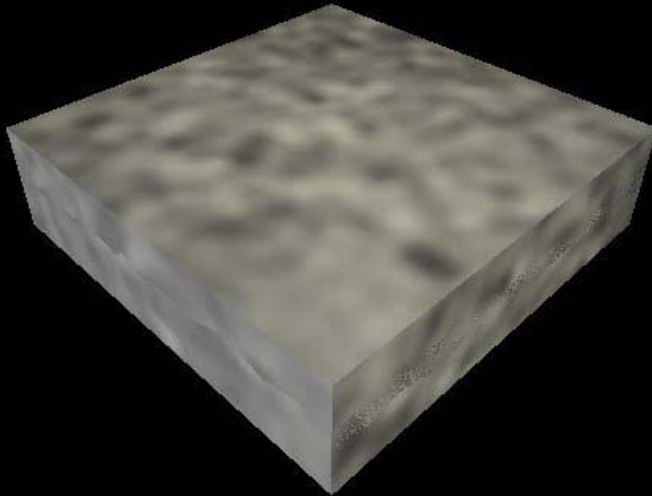
[NASA, NSF and
Smithsonian Institution]



Carbonate-Magnetite Assemblages in ALH84001



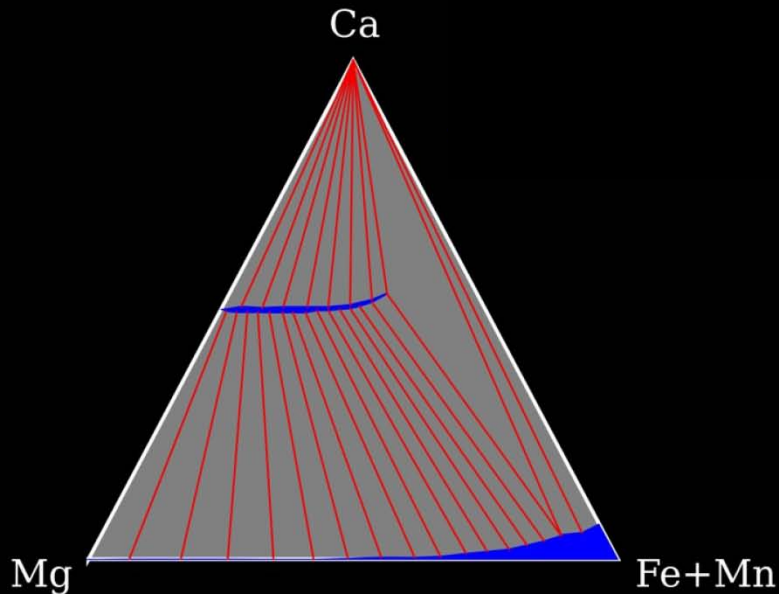
Shape and Location of Carbonate in Orthopyroxene



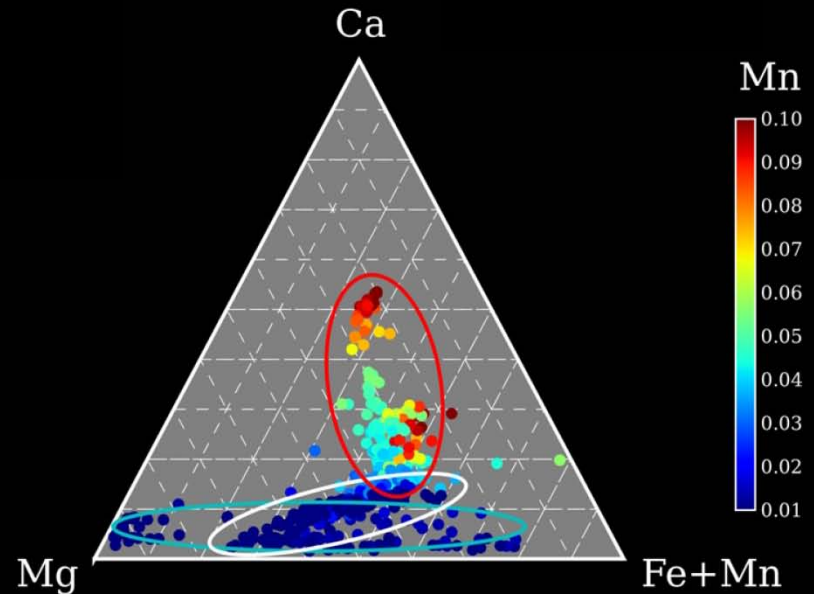
Inverted Conic Frustrum

Cation Composition of ALH84001 Carbonates

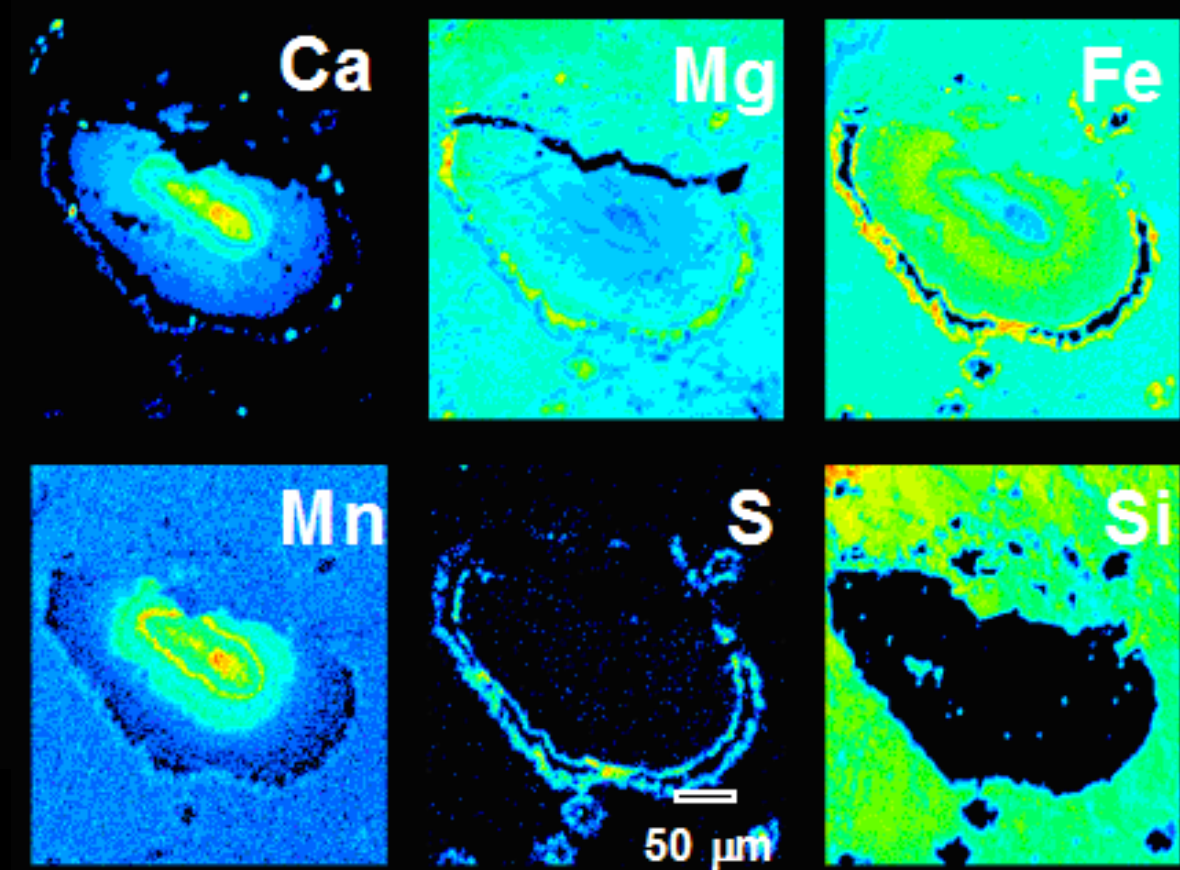
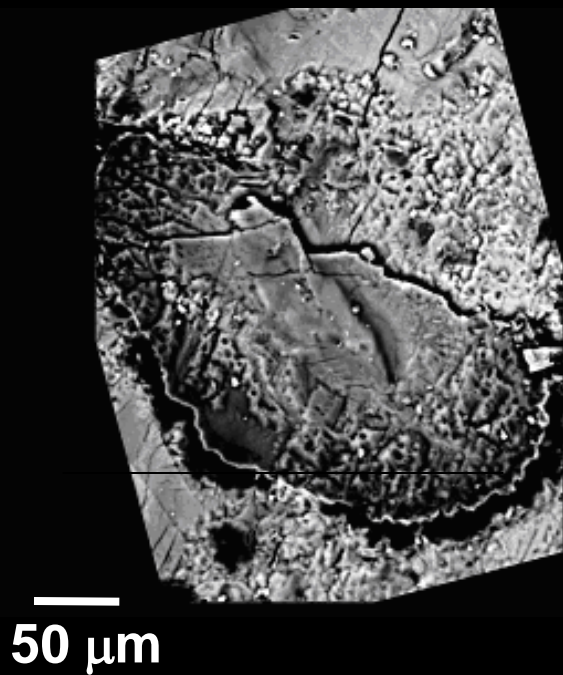
Terrestrial Carbonates



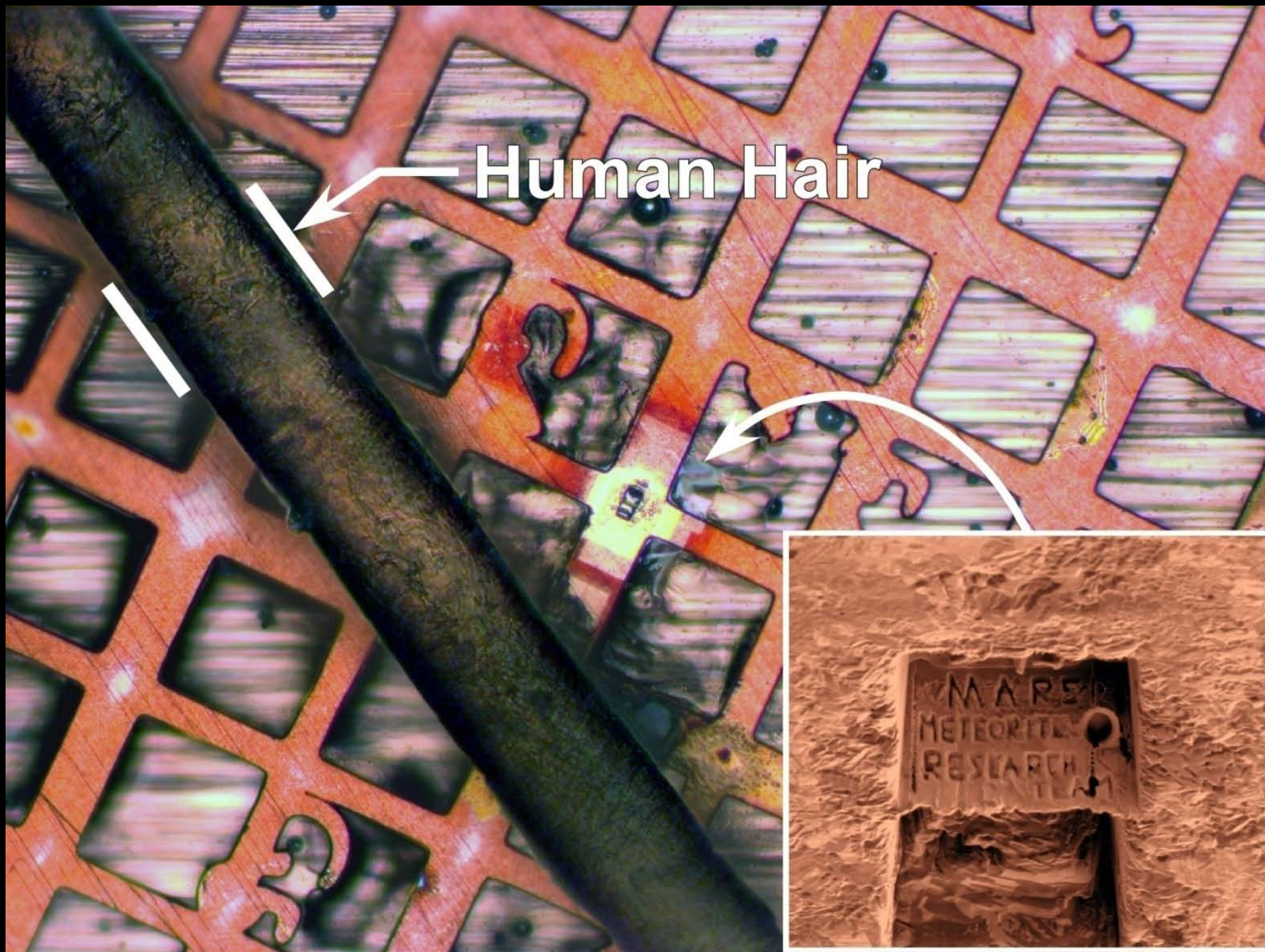
ALH84001 Carbonates



Oscillatory Chemical Zonation of ALH84001 Carbonate Disks

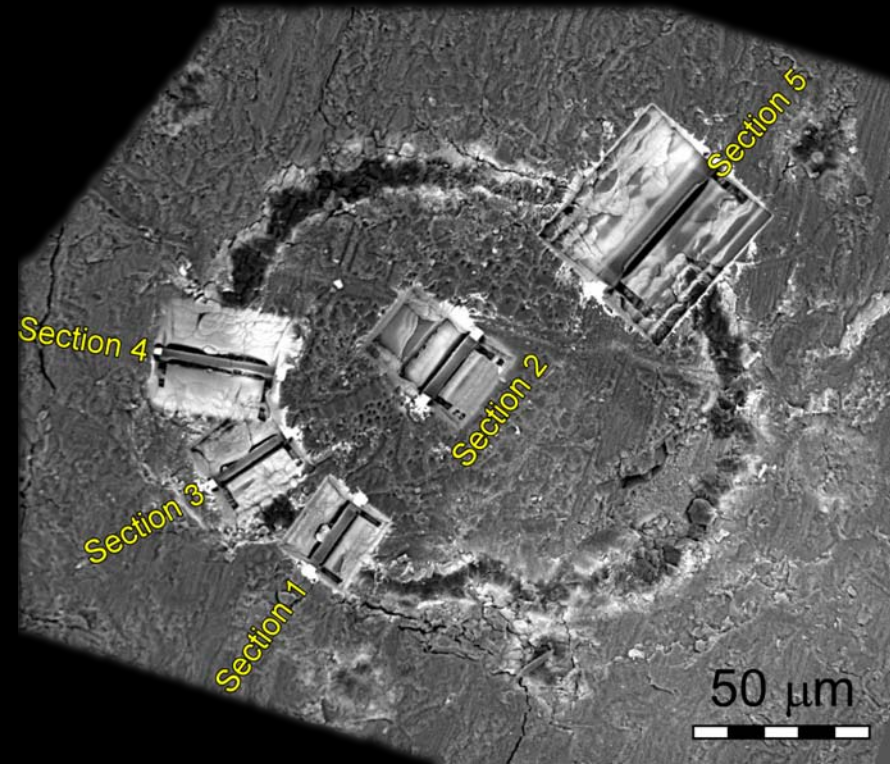
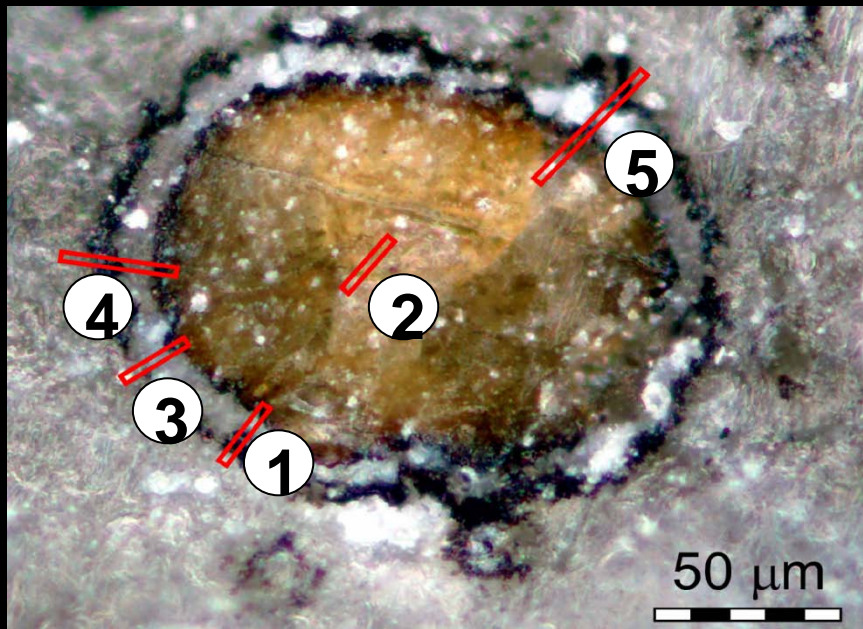
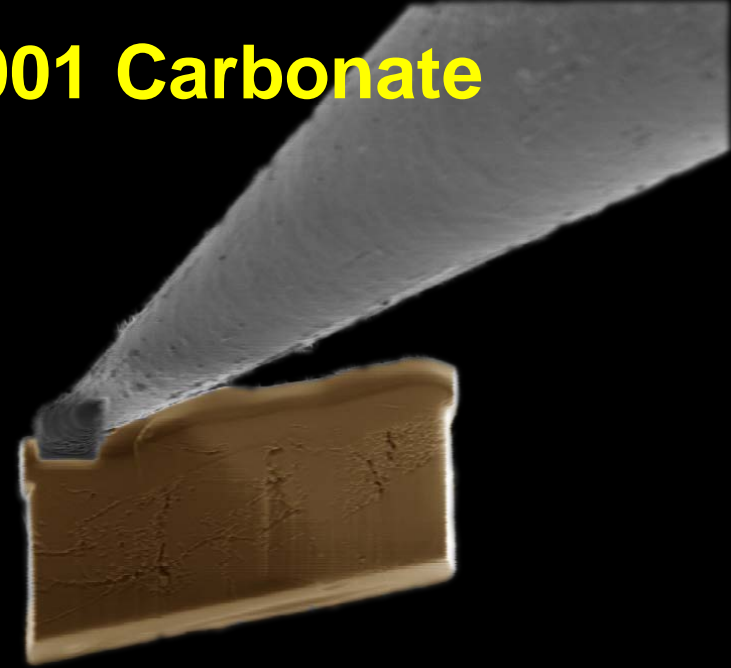


Working in the Nano-Scale World

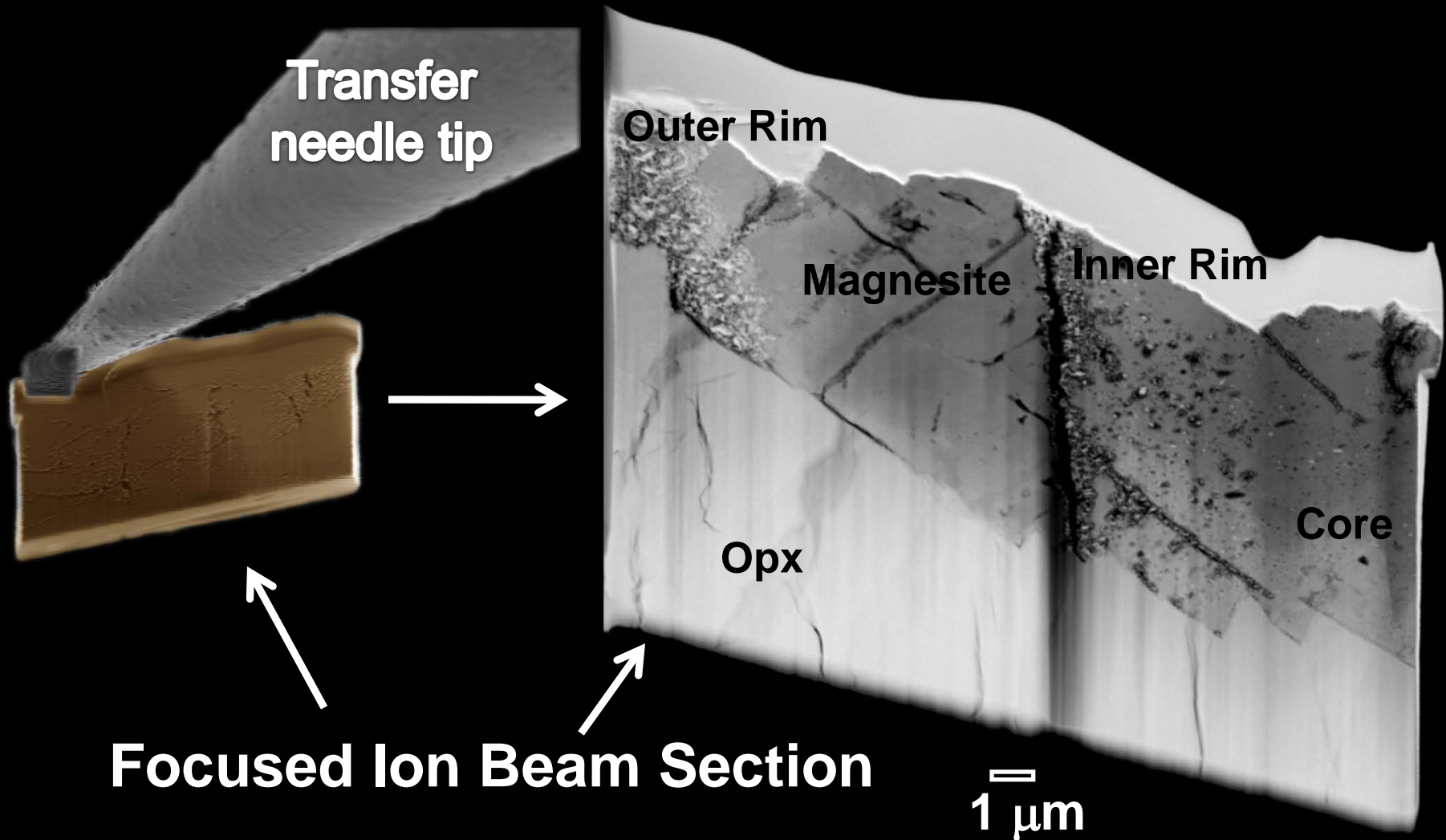


FIB Microscopy of ALH84001 Carbonate

FIB = Focused Ion Beam

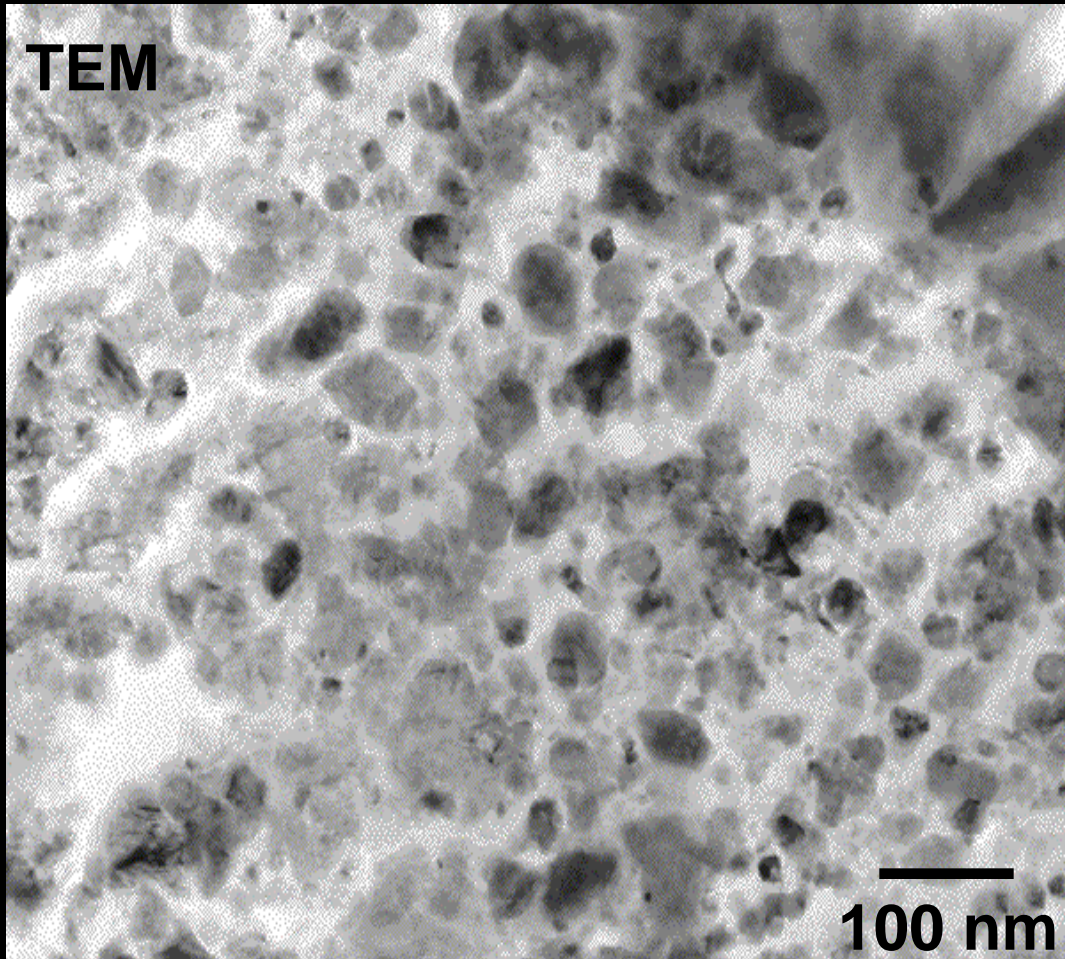


Preservation of Sample & Spatial Relationships



ALH84001 Magnetite Distribution

Disk Rims & Veins

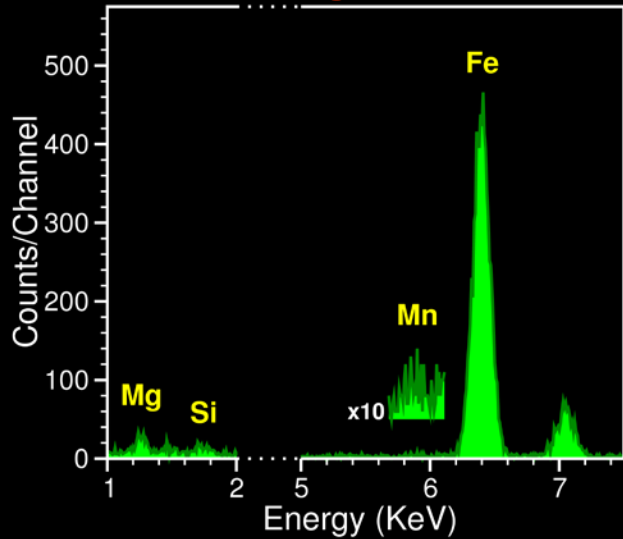


Disk Center

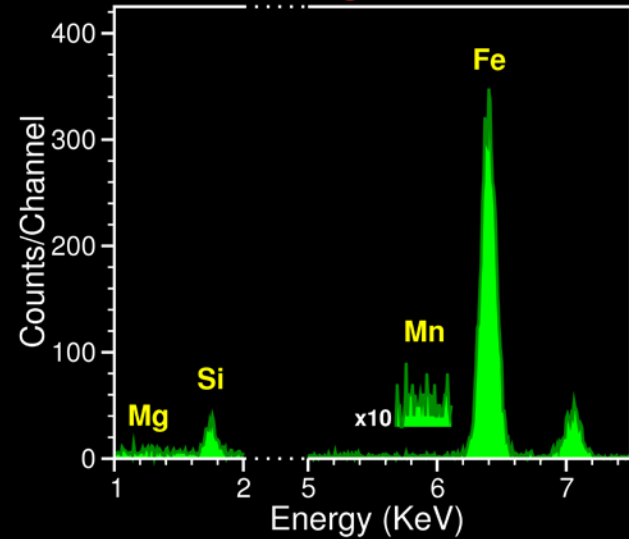


Composition of ALH84001 Magnetite & Carbonate

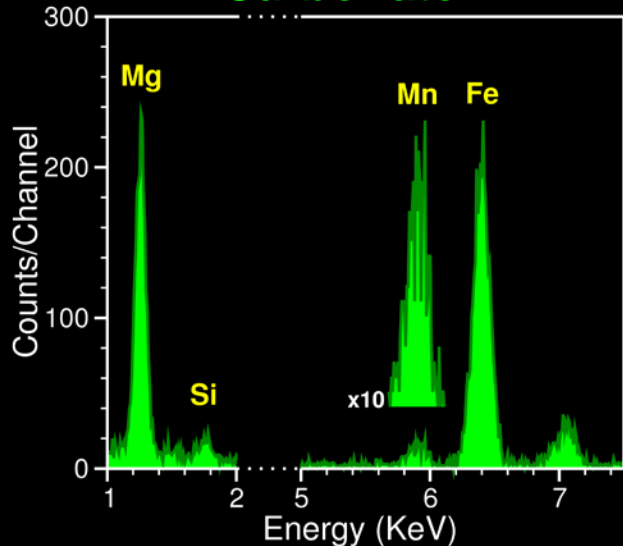
Magnetite



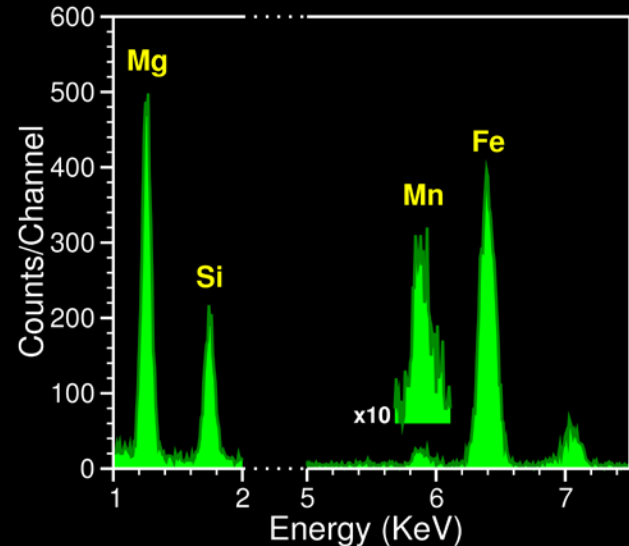
Magnetite



Carbonate

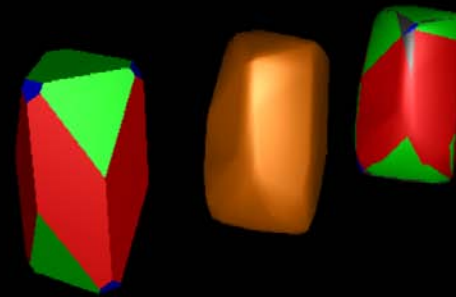
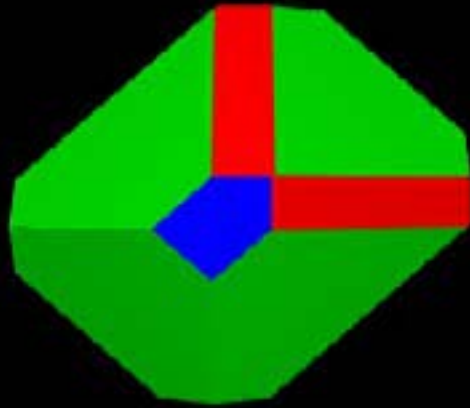


Carbonate



ALH84001

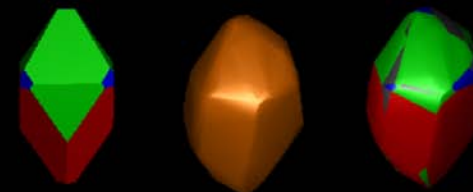
Truncated Hexaoctahedral Magnetite from Mars



$[10\bar{1}]$ Zone Axis



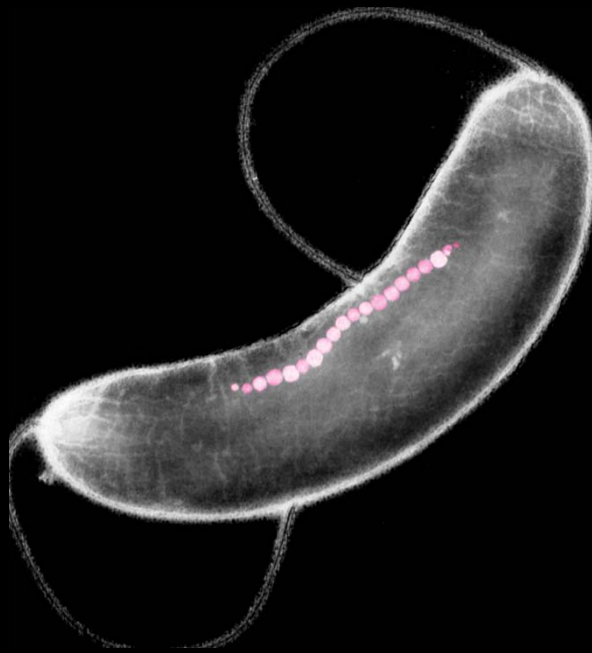
$[111]$ Zone Axis



$[110]$ Zone Axis

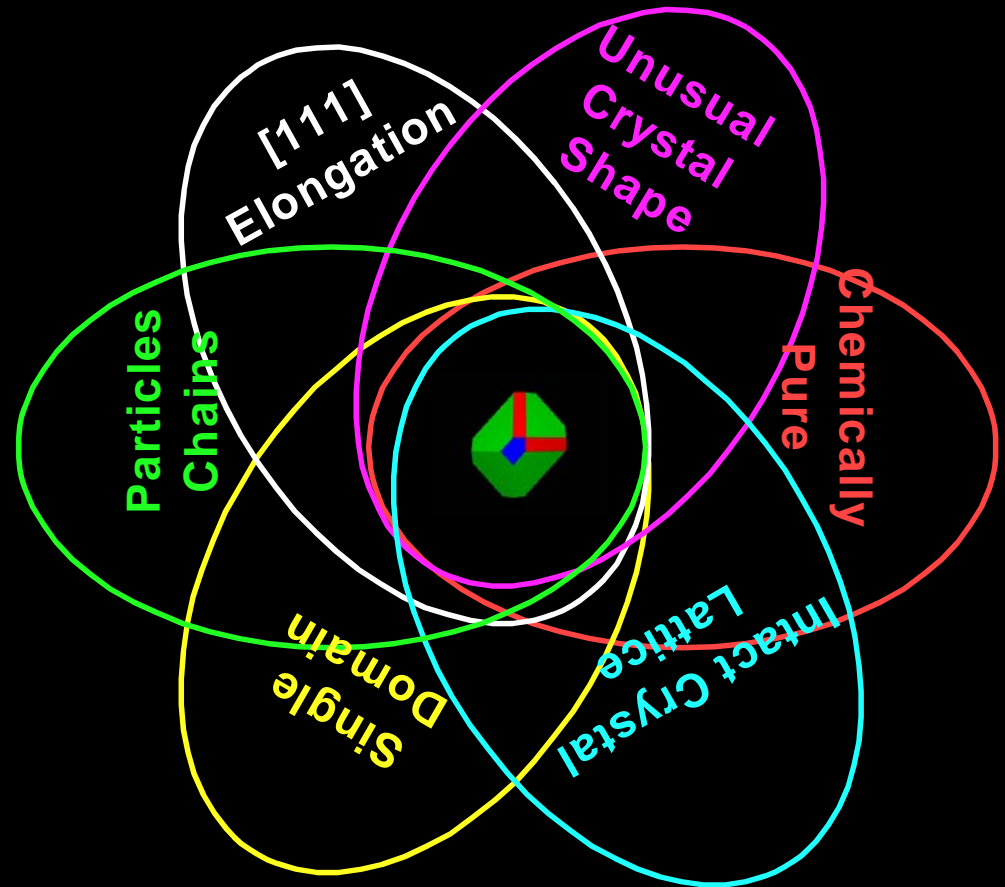
MAGNETITE AS SIGNATURE OF LIFE

MAGNETOTACTIC BACTERIA



200 nm

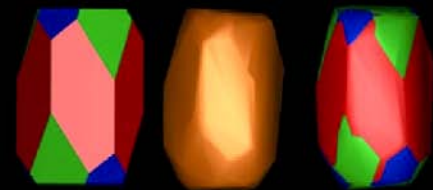
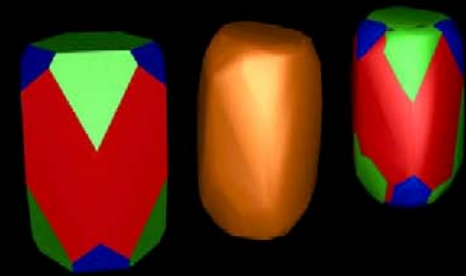
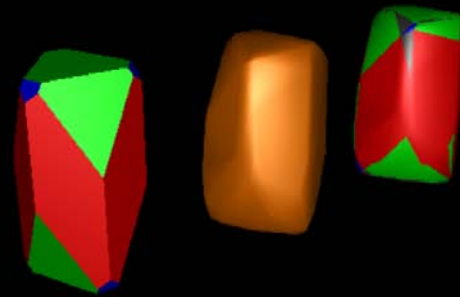
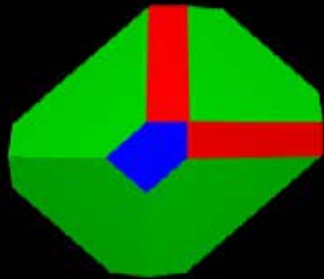
Six Properties of Biogenic Magnetite



ALH84001

MV-1

**Comparison of
Mars magnetite
with MV-1
biogenic
magnetite**



$[10\bar{1}]$ Zone Axis

$[10\bar{1}]$ Zone Axis

$[111]$ Zone Axis

$[111]$ Zone Axis

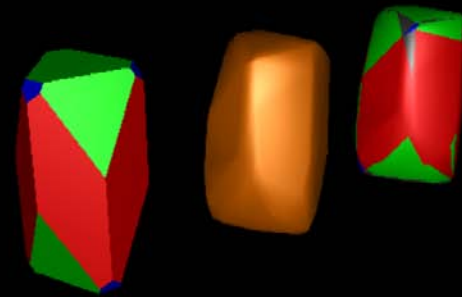
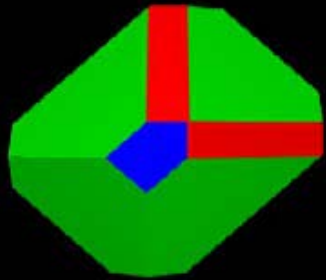
$[110]$ Zone Axis

$[110]$ Zone Axis

ALH84001

MV-1

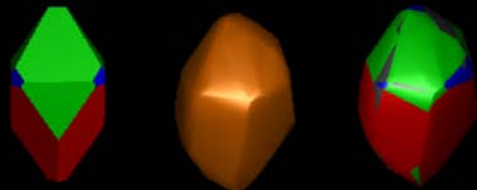
Comparison of
Mars magnetite
with MV-1
biogenic
magnetite



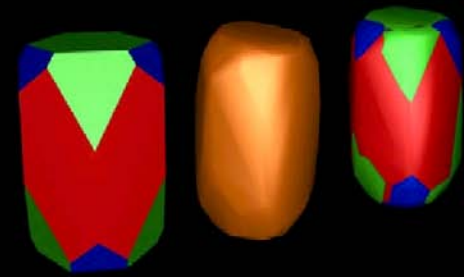
$[10\bar{1}]$ Zone Axis



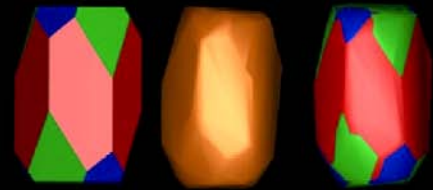
$[111]$ Zone Axis



$[110]$ Zone Axis



$[10\bar{1}]$ Zone Axis



$[111]$ Zone Axis



$[110]$ Zone Axis

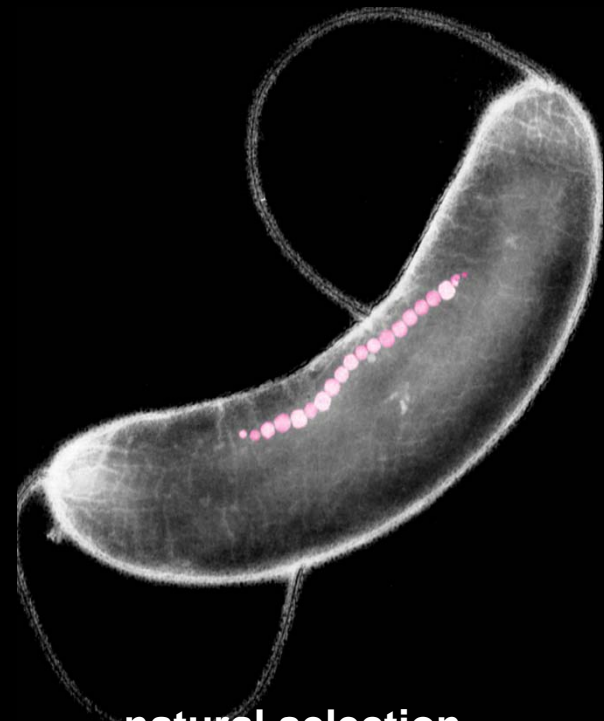
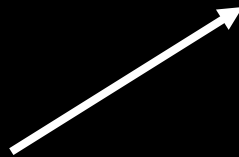
IDENTICAL!

Terrestrial Magnetite (Fe_3O_4)

*two processes produce
magnetites that display
different physical and
chemical properties*

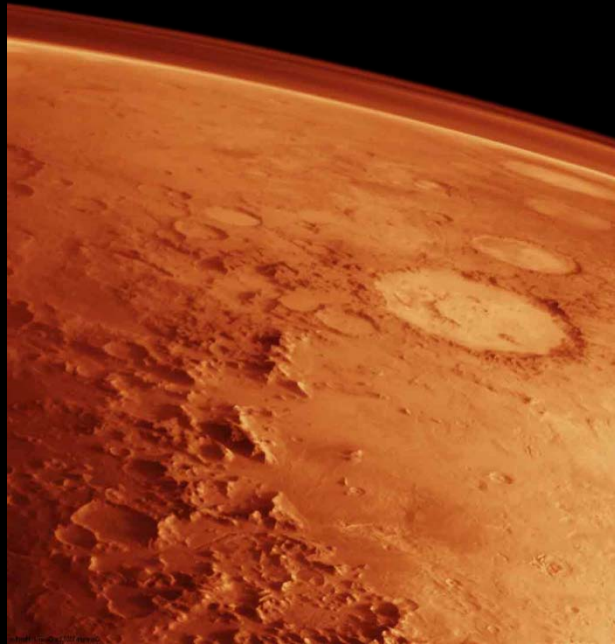


thermodynamic & kinetic constraints



natural selection

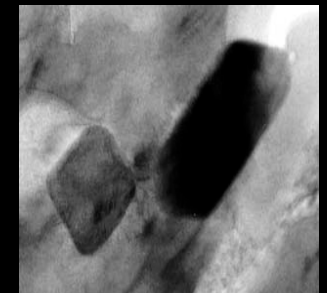
The Debate: Origin of ALH84001 Magnetite



1 cm



$2 \cdot 10^{-2}$ cm



$5 \cdot 10^{-6}$ cm

When and how did ALH84001 magnetite form?

Allochthonous components?

Partial thermal decomposition of carbonate?

Could Heating of the ALH84001 Disks Produce Magnetites?

Fact 1: pure siderite converts to pure magnetite when heated

Fact 2: impure siderite converts to impure magnetite when heated

(These facts are supported by dozens of experiments and dozens of published peer-reviewed papers)

Could Heating of the ALH84001 Disks Produce Magnetites?

Fact 3: ALH84001 carbonates contain
embedded pure magnetites

Fact 4: ALH84001 carbonates include only
impure siderites, do not include pure
siderites, and never did

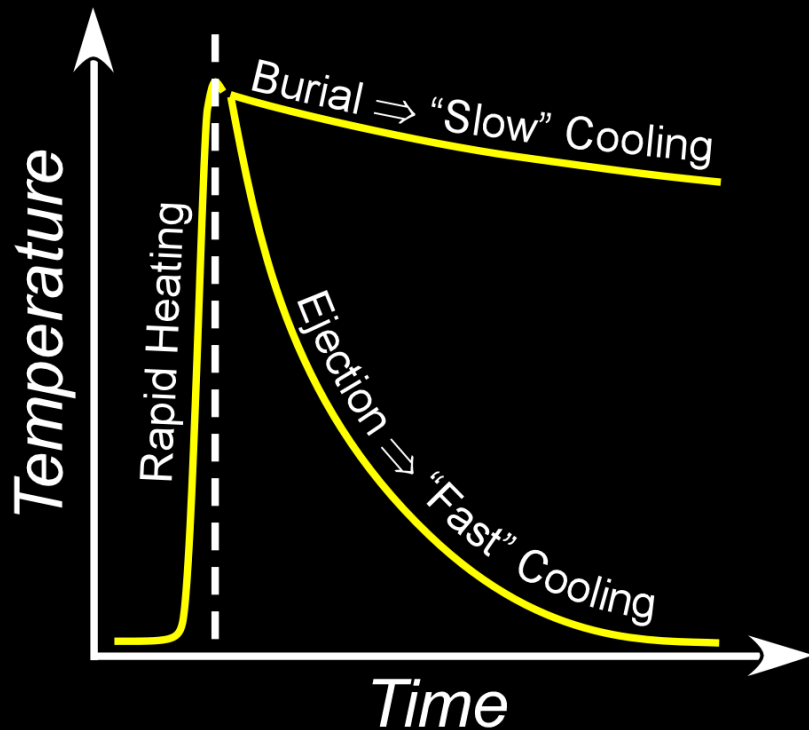
Could Heating of the ALH84001 Disks Produce Magnetites?

**Logical conclusion 1: ALH84001 magnetites
were not made from ALH84001 carbonates**

**Logical conclusion 2: ALH84001 magnetites
were made by another process**

**Important observation: On Earth, magnetites identical to
most of the ALH84001 magnetites are made *only* by
bacteria and such magnetites are considered strong
biosignatures wherever they are found**

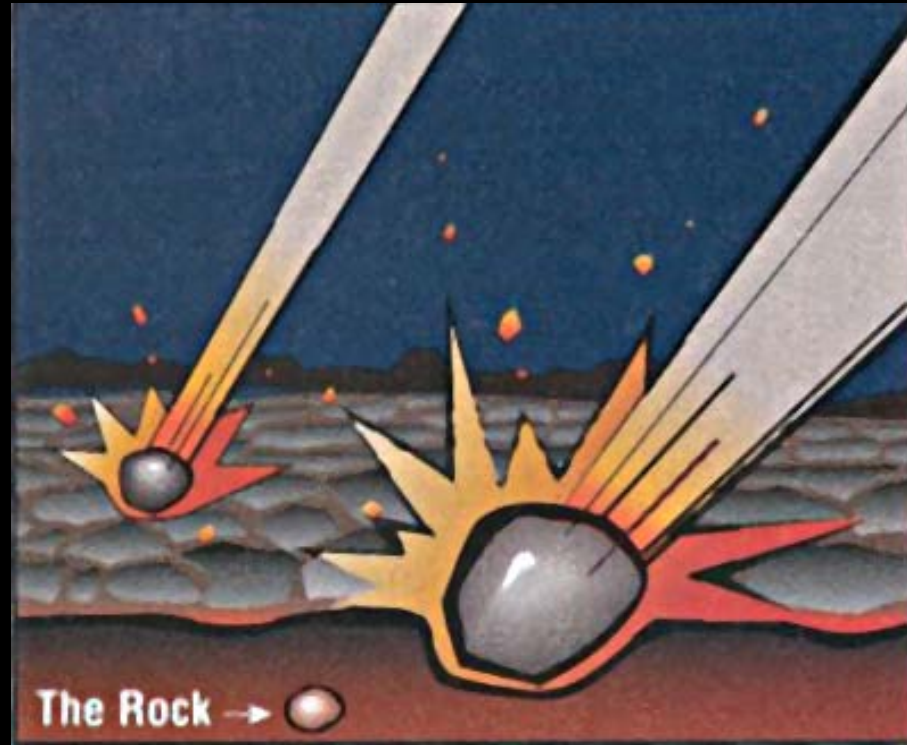
Two proposed Heating Scenarios...Contradictory



"Fast" Cooling – Kinetic Control

"Slow" Cooling – Thermodynamic Control

Proposed “Slow” Cooling Scenario



- Shock heated to $\sim 500 - 700$ K
- Cooling occurs while buried in regolith

Phases Formed In Slow & Fast Cooling Scenarios



Consequences	Cooling Under “Fast” Cooling	Cooling Under “Slow” Cooling	ALH84001 Observations
Carbonate Zonation	✓	✗	✓
Graphite Precipitation	✗	✓	✗
Chemically Pure Magnetite	✗	✓	✓

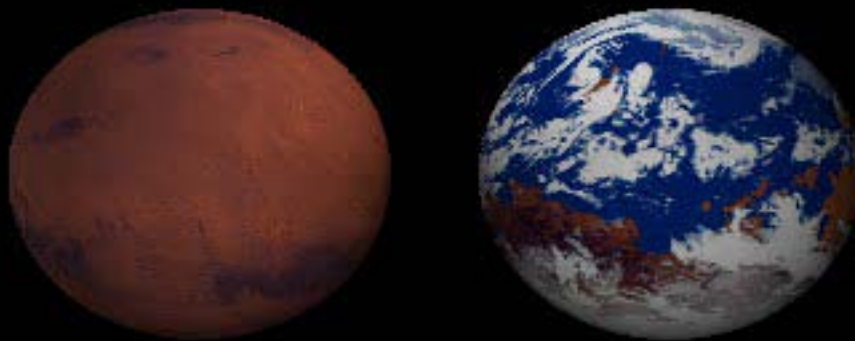
Summary

- Properties of terrestrial magnetites can be used to constrain their origin \Rightarrow ***Robust Biosignature***
- Most profound implication of this study is that a significant proportion of the magnetite crystals embedded in the carbonate assemblages in Martian meteorite ALH84001 require the intervention of biology to explain their presence

**...Life existed on ancient Mars.
If true, life may exist on Mars today..**

***It may actually be quite hard to
extinguish subsurface microbial life,
even by impact, and in that respect,
both the Earth and Mars would be
likely to hang onto at least the
microbial part of their biosphere***

***Jack Farmer, NASA- Ames Research Center Now at
Arizona State University, Tempe, Arizona***



Summary & Conclusions

- Thermal decomposition hypothesis cannot explain the majority of ALH84001 magnetites
- ALH84001 magnetites are consistent with detrital origins
- Biogenic model viable



Why Missions to Mars?

**“1500 years ago everybody KNEW the Earth was
the center of the universe,
500 years ago everybody KNEW the earth was flat,
and 15 minutes ago you KNEW that humans were
alone on this planet...**

Imagine what you will know tomorrow”.

“Agent K” from the movie “Men in Black”

Observations from Mars—More Diverse Than Previously Thought!

Ancient life—potential has increased

- Lots of ancient liquid water, surface and ground
- Potential for fossil preservation

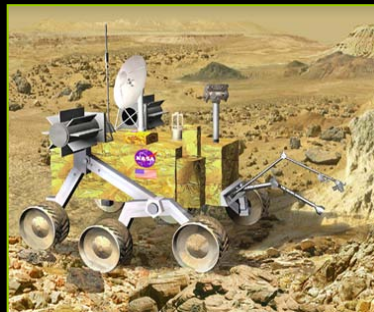
Modern life—possible

- Equivocal evidence of modern surface liquid water—probable liquid water in deep subsurface
- Methane may be a critically important clue to subsurface biosphere

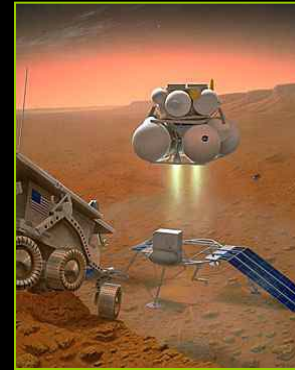
Progression to “Seek Life Beyond”



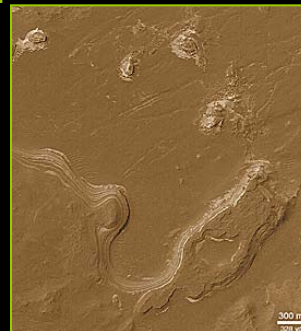
Follow the water...



Follow the carbon...



**Send humans...
search for life & extend
life to there**



Find ancient habitats...

**Sample the rocks...
search for life and biosignatures**

Launch Year

Operational

2009

2011

2013

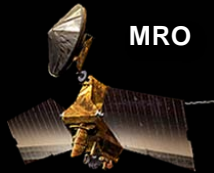
2016

2018 & Beyond

The Era of Mars
Sample Return?



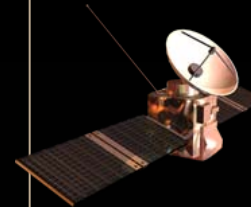
Odyssey



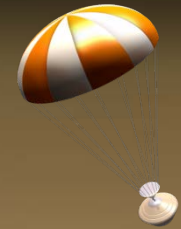
MRO



Mars Express
Coop



MAVEN



Lander
Mission X



MER



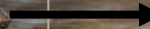
Phoenix



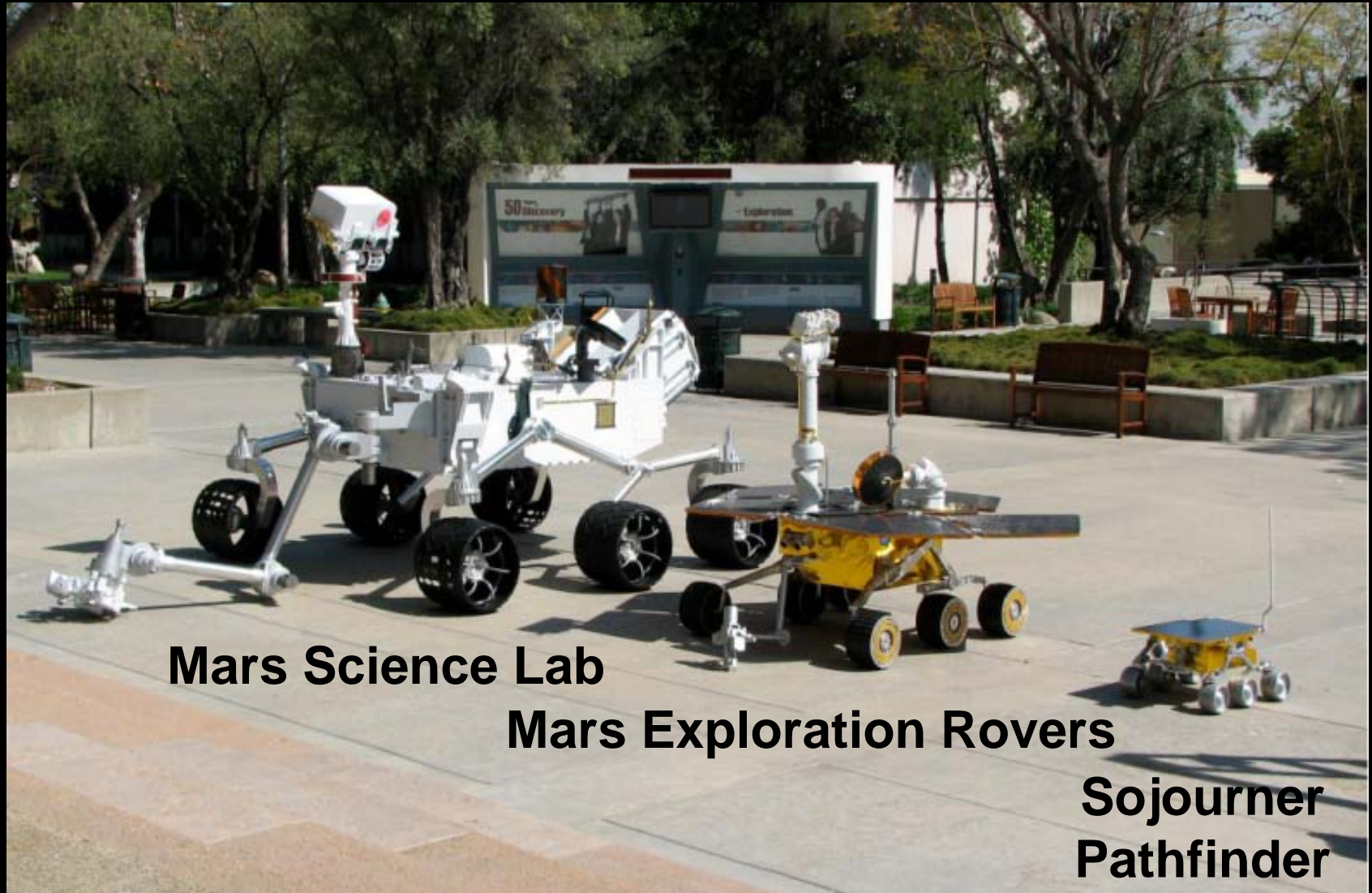
Mars Science Lab



ESA/ExoMars
Cooperation



MSL will carry an analytical laboratory of unprecedented capability!

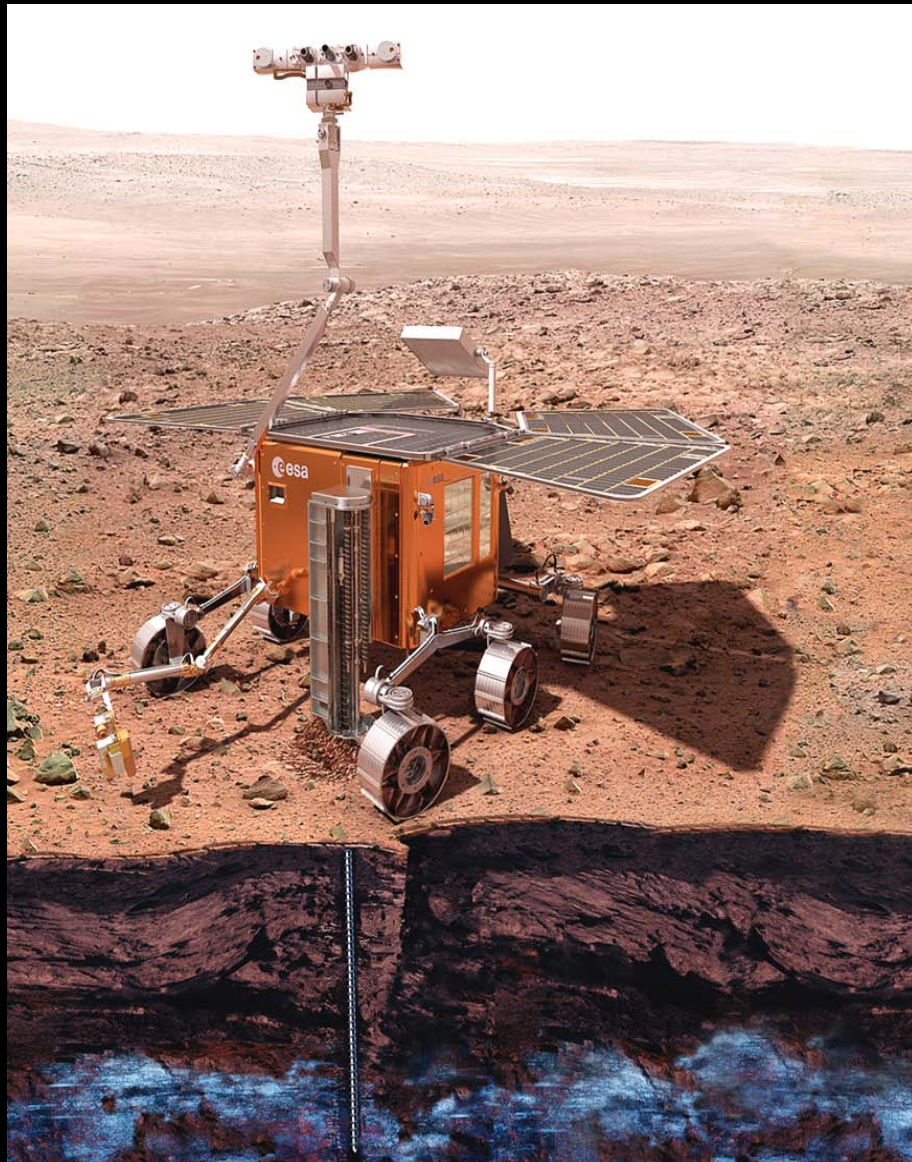


Mars Science Lab

Mars Exploration Rovers

**Sojourner
Pathfinder**

ExoMars 2018 will have mobility and access to the subsurface!



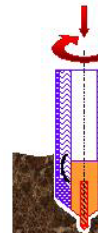
*Europe Plans
To Go To MARS!*

But

*Complexity
Causes Delays!*

DRILLING TO REACH
SAMPLING DEPTH

CENTRAL PISTON
IN UPPER POSITION



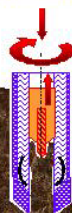
1

CORE FORMING



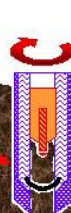
2

CORE CUTTING
(closing shutters)



3

CORE FORMING



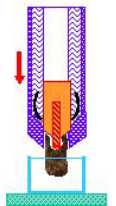
4

DRILL UPLIFT



5

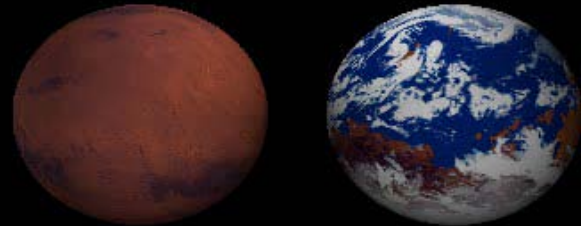
SAMPLE
DISCHARGE

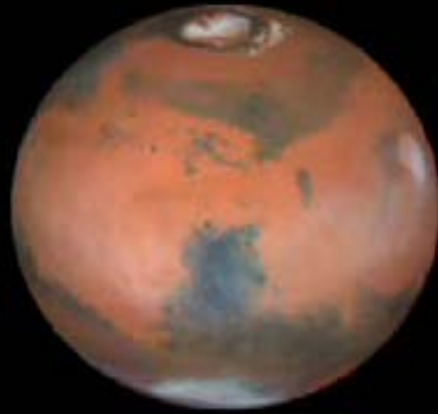


6

“A Renewed Spirit of Discovery”

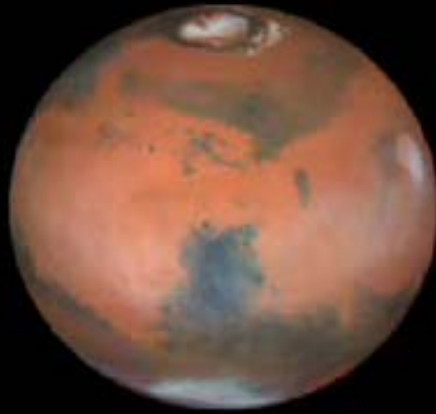
- **Human Lunar mission in 2020 or so**
- **Human missions to Mars (when the technology is ready)**
- **Robotic missions will serve as “trailblazers” for humans**





“Sometimes I think I flew to the wrong place. Mars was always my favorite as a kid and it still is today. I’d like to see Mars become the focus, just as John F Kennedy focused on the moon.”

**Buzz Aldrin
July 20, 2009**



“The possibility of life on Mars is too thrilling for mankind to ignore.”

The Economist, Jan 22, 2009

**“Science is the search for truth —
it is not a game in which one tries
to beat his opponent...”**

Linus Pauling